Federal Aviation Administration

AACE

Airworthiness Assurance Center of Excellence

Aircraft Catastrophic Failure Prevention Program

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Uncontained Engine Failure Research

Sioux City, 1989

Figure 3.--Photo (C. Zellmer) taken while flight 232 was approaching Sioux Gateway Airport. Arrows indicate damage to the right horizontal stabilizer. It is also evident that the No. 2 engine fan cowl door and the tail cone are missing.

Uncontained Engine Failure Research
Fan Disk, 1989

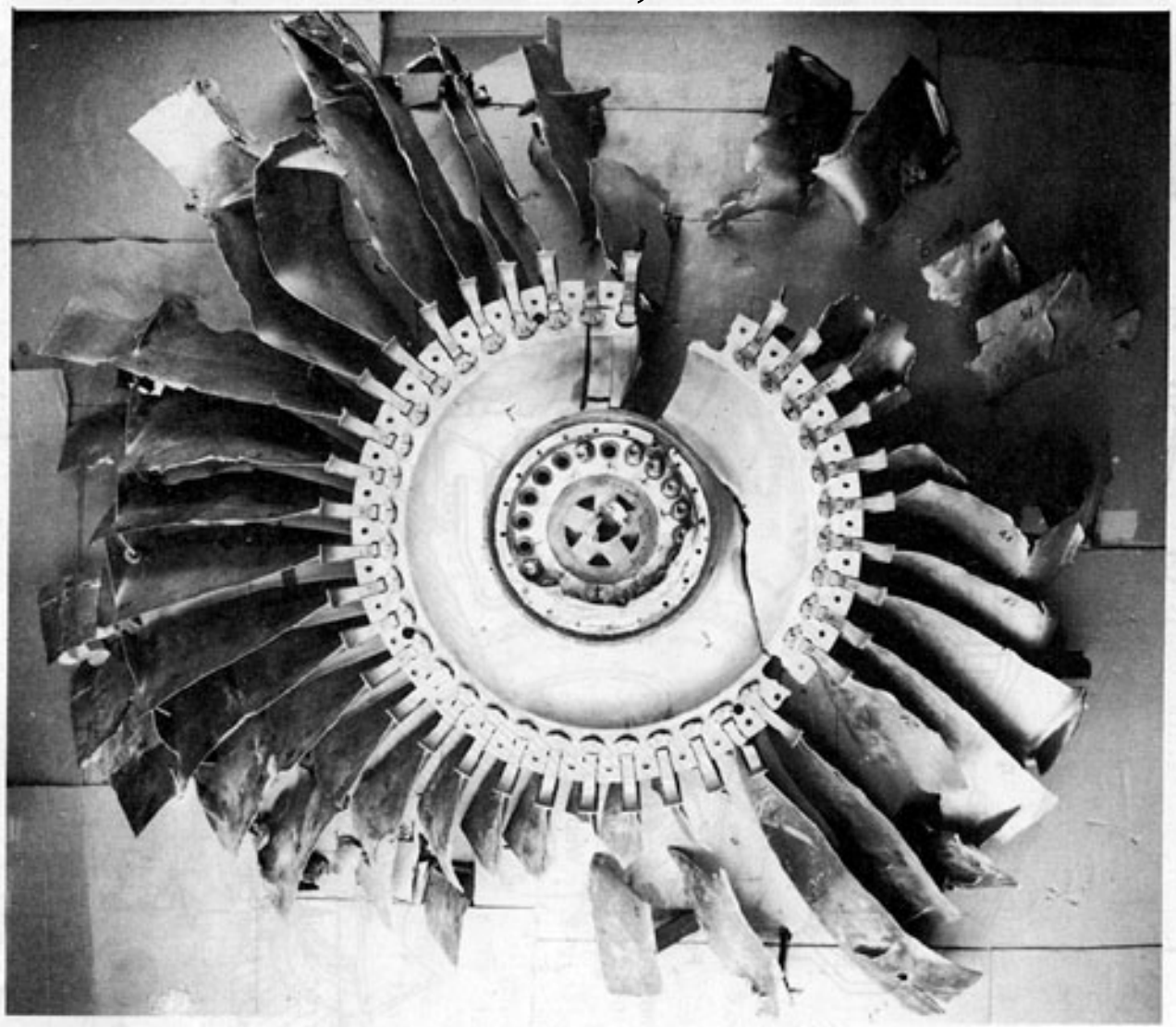
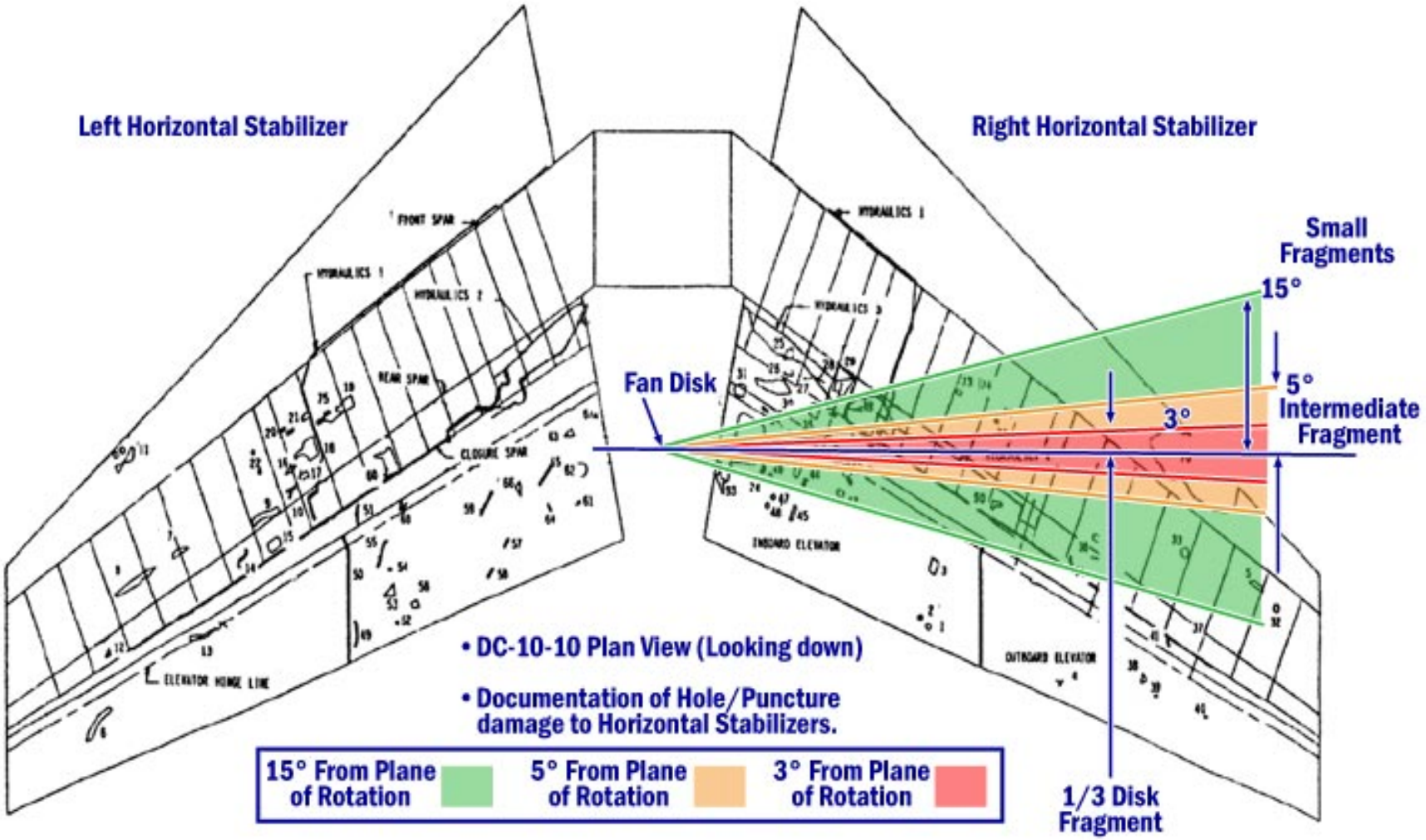


Figure 18.--No. 2 engine stage 1 fan disk (reconstructed with blades).

Uncontained Engine Debris



NTSB Findings-
SIOUX CITY 1989

- #2 (center) engine uncontained failure
  - Compressor disk material defect in manufacturing
  - Maintenance Inspection of compressor disc
- Uncontained debris from engine damaged all three aircraft hydraulic systems

FAA R&D Program Background
Aircraft Catastrophic Failure Prevention Program (ACFPP)

- **ACFPP was created by Congressional direction after the 1989 Sioux City Accident**
- **Objective-**
  - **Conduct research that will reduce the risk of catastrophic aircraft accidents and fatalities**
- **Uncontained engine failure research has been primary focus**
  - **Mitigation of smaller fragments**
- Other research programs concentrated on disc material and inspection improvements

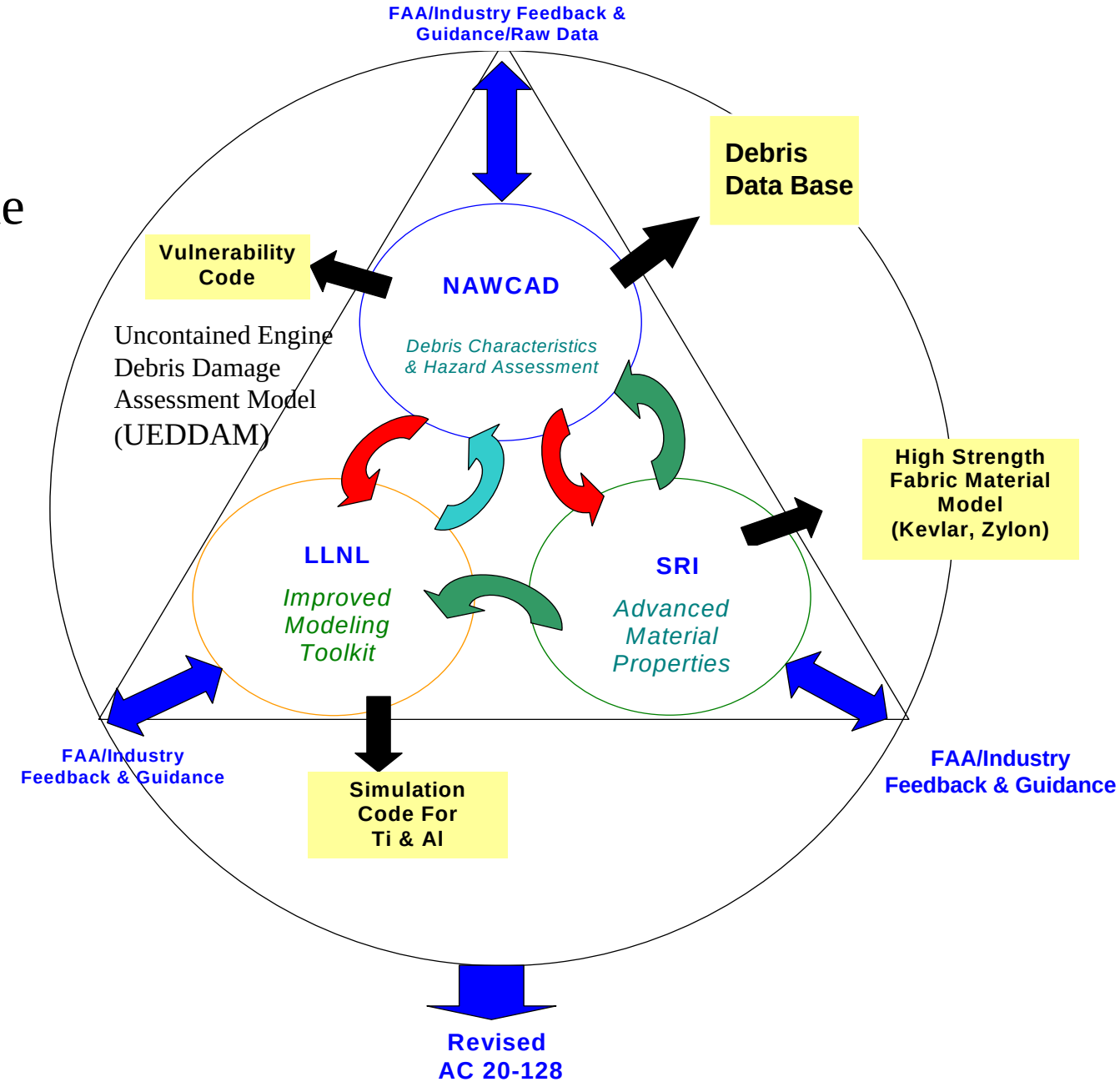
Uncontained Engine Debris Mitigation Program

- NTSB Recommendations from Sioux City
  - ***Aircraft Vulnerability-*** Develop and maintain a database of uncontained engine debris impacting aircraft that would benefit design assessments and safety analysis
  - ***Failure Mitigation-*** Update AC-20-128 to mitigate uncontained engine debris from new aircraft certification
    - multiple fragments
    - Non-linear finite element modeling

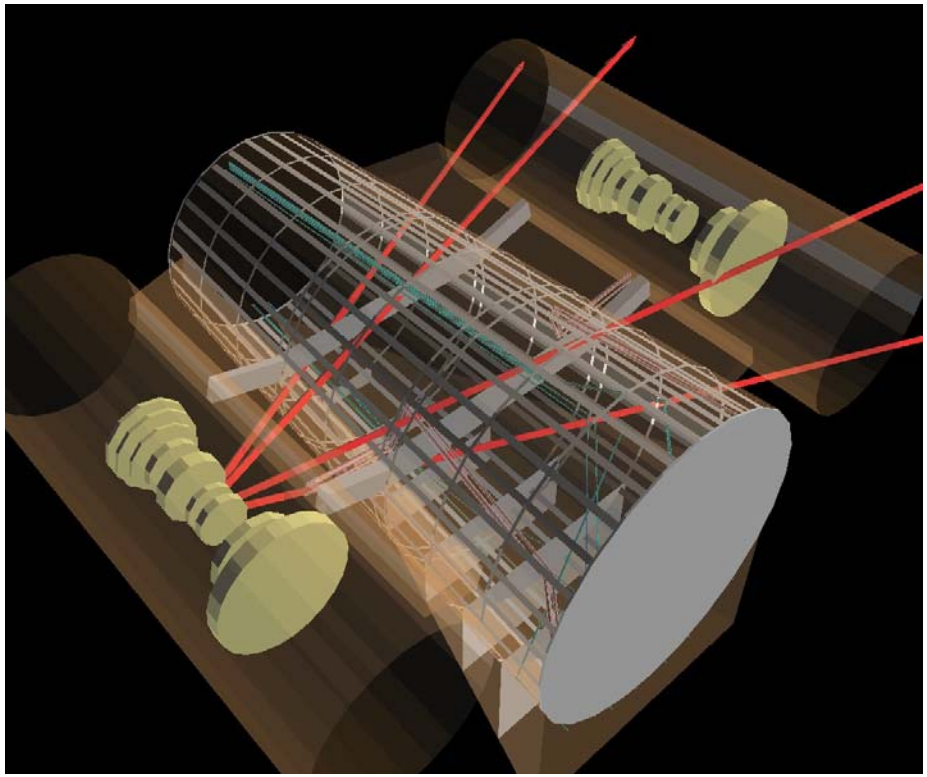
RPD 516 - Uncontainment Research: Airplane Focus

Uncontained Engine Debris Mitigation Program

- **NTSB A 90-170**, revise AC-20-128 (new aircraft designs)
- **NTSB A 90-172**, Develop data base of uncontained debris



Uncontained Engine Debris Damage Assessment Model (UEDDAM) Trajectories



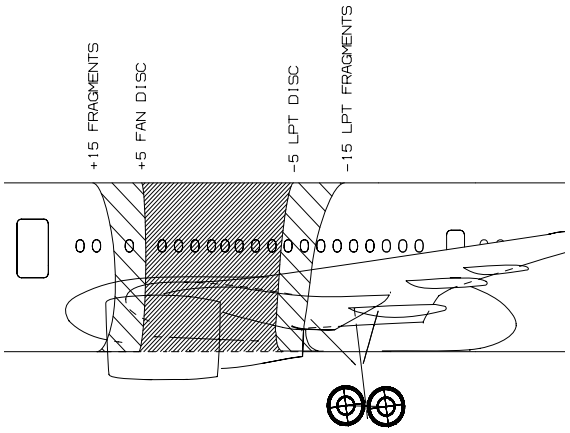
UEDDAM model repeats event multiple times.
Varies trajectories and orientation each time.

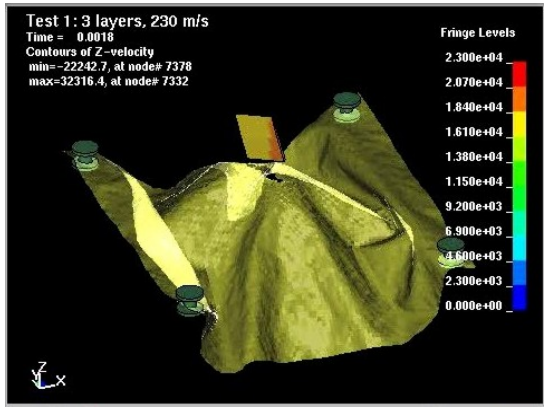
AACE University / Industry Partnerships

- 2001 Uncontained Engine Workshop presented results of FAA sponsored research
- In Order to Transition this Technology into service, partnerships were formed between academia, government, and industry using AACE Cooperative Agreements
- 100 Percent Cost matching achieved *(primarily by industry partners)*

AACE University / Industry Partnerships (2002 start)

- **UC Berkeley** partnered with Boeing, SRI International and Lawrence Livermore National Laboratory (LLNL)
- ***Research Area*** - material development and modeling for aircraft barriers (metals, fabrics, composites)

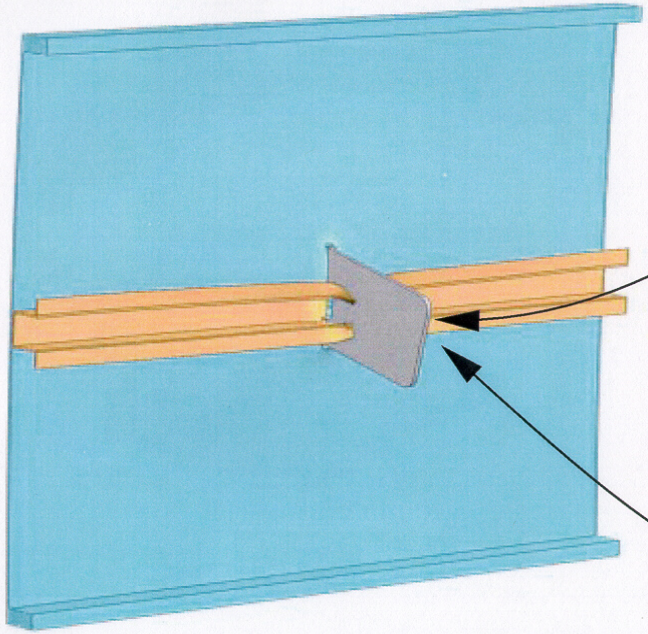


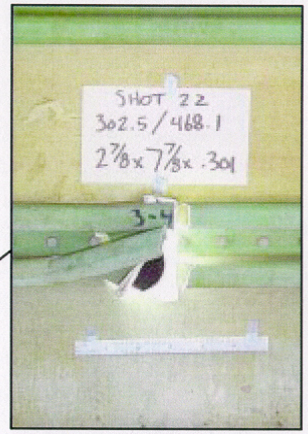


AACE Technology Transfer
Engine Fragment Shielding Project

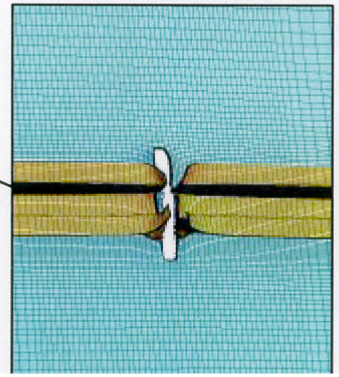
New 2024−T3 Aluminum failure parameters used to simulate Chinalake *Engine Debris Fuselage Penetration Testing Phase 1:* Test 22 − *Fan blade fragment impact with skin/hat section*

Initial blade fragment velocity = 795 ft/sec





Residual fragment velocity = 725 ft/sec

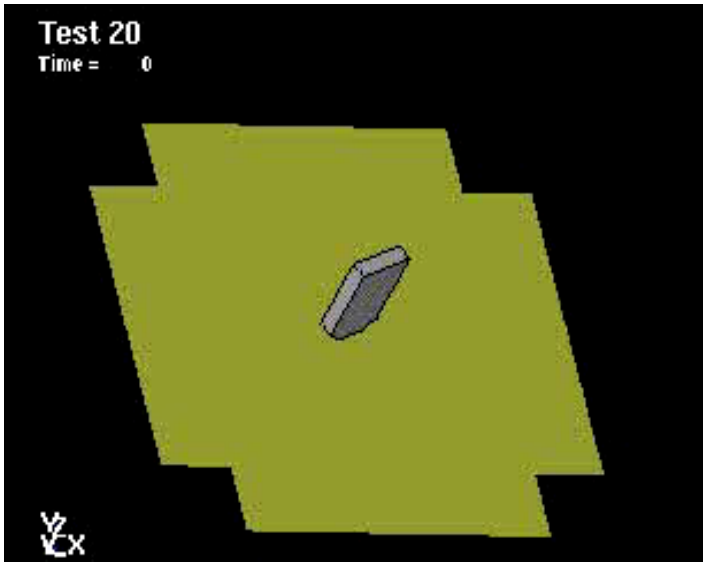


Residual velocity = 715.833 ft/sec −1.26% deviation from the measured value.

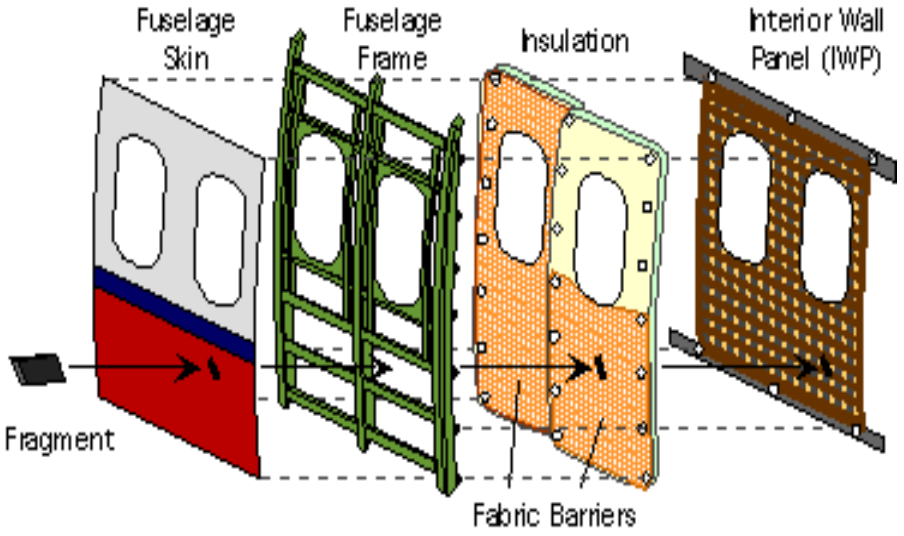
The mesh contained 122,625 nodes and 94,420 elements. The rivets were not modeled in the simulation.

AACE University / Industry Partnerships (cont'd)

Simulation



Barrier Concept

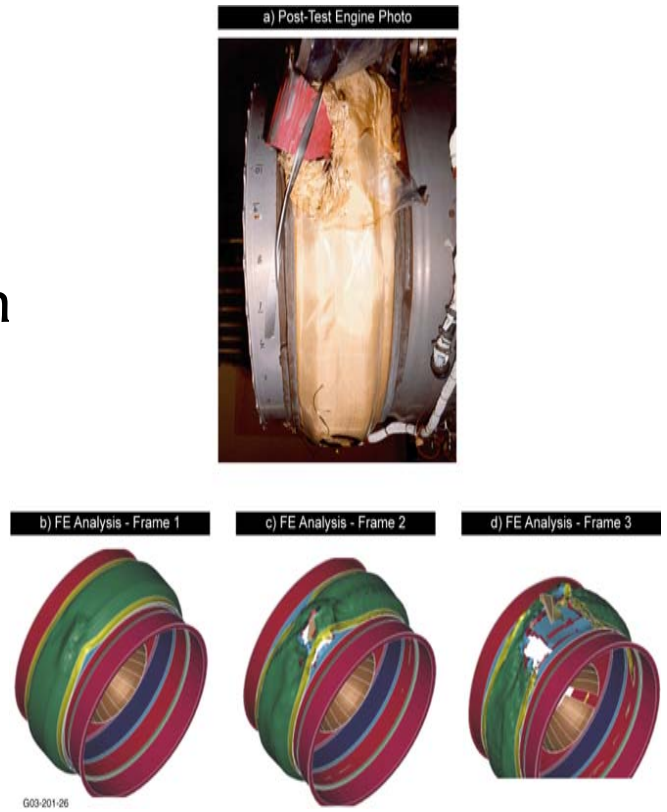


AACE University / Industry Partnerships (2002 start)

- **Arizona State University**

partnered with Honeywell ,
SRI International and NASA Glenn

- ***Research Area***- turbine engine fabric containment modeling



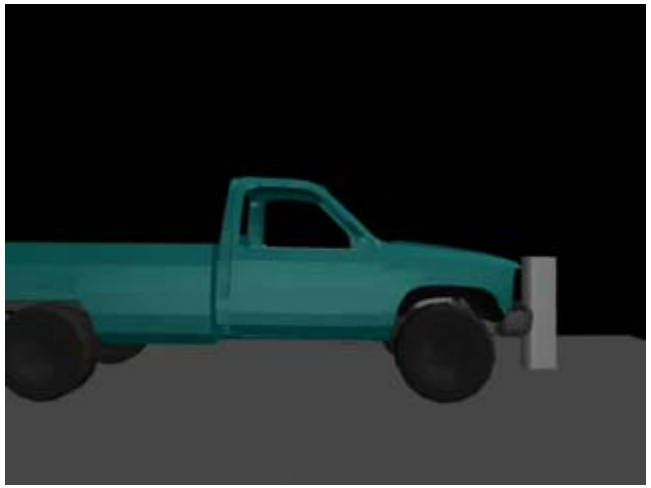
LESSONS LEARNED

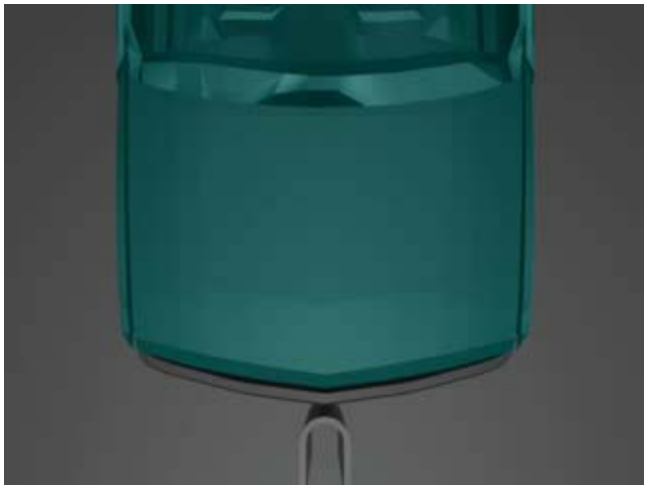
FROM ASU / UCB PROGRAMS

- **LS-DYNA can give significantly different results based on Model version and computer platform**
- LS-DYNA Model has extensive Quality Control Program for the Automotive Industry
  - **No such Quality Control Program existed for the Aircraft Industry**
- FY 2003, a Joint FAA / NASA sponsored Workshop established an Aerospace Quality Control Working Group with Industry (Engine / Airframe Manufacturers)

AACE University / Industry Partnerships (2004 start)

- **George Washington University** partnered with Livermore Software Technology Corp (LSTC) and Silicon Graphics Inc. (SGI)
- ***Research Area-*** LS-DYNA Aerospace Working Group Quality Control Support
- National Crash Analysis Center: www.ncac.gwu.edu



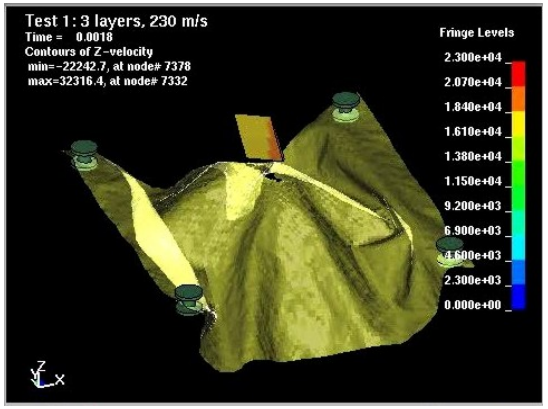


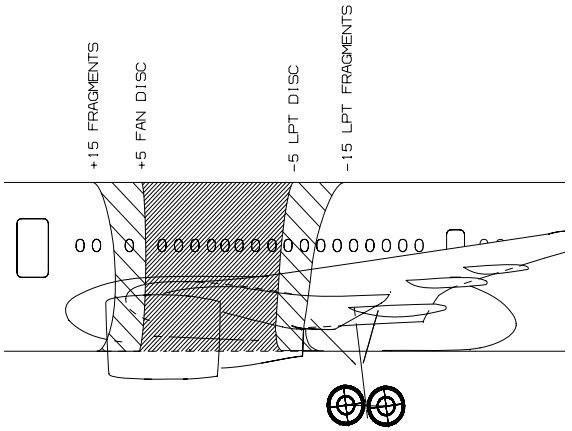
AACE Technology Transfer
Engine Fragment Shielding Project

- ***"Modeling, Analysis and Testing of Metallic and Composite Shielding"***
- AACE Project started in FY-02 (Phase 1)
- **Team: UC Berkeley (Prof T. Zohdi PI), Boeing, LLNL**
  - ***Purpose-*** To develop an accurate LS DYNA3D model for aircraft materials and barriers using metals, composites, etc.
  - ***Accomplishments (Phase 1)(FY-02-04)***
    - Completed ballistic testing on aluminum at UCB and LLNL
    - Boeing modeled ballistic tests using Livermore improved material model
  - ***Status for FY-04 (phase 2)(FY-04-06)***
    - Composite testing and modeling is prime focus. Titanium will also be evaluated for thick plates. Ballistic and material testing is currently in progress at UC Berkeley and LLNL.

Technology Transfer - Lightweight Ballistic Protection on Commercial Aircraft

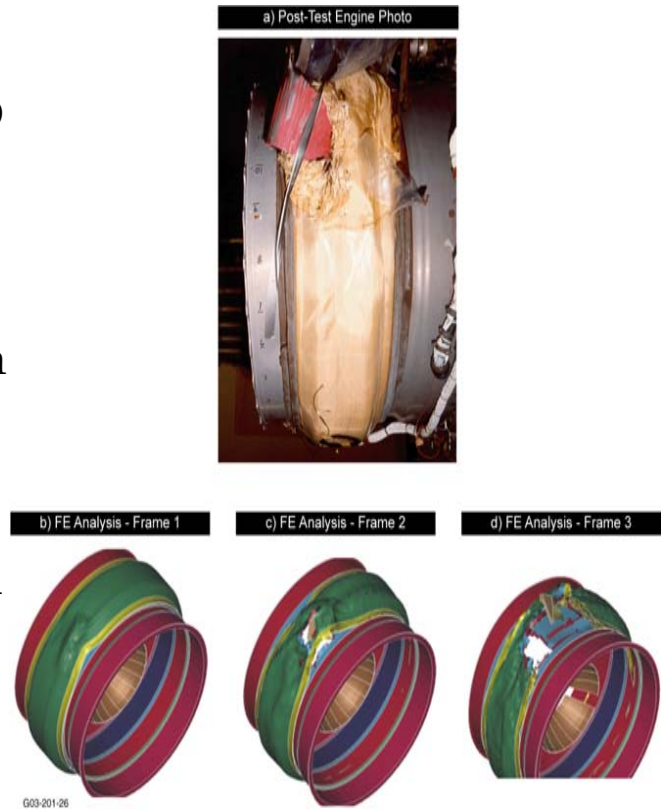
- **Team: UCB, (Prof. T. Zohdi PI),** Boeing, SRI International
  - ***Purpose-*** Determine the suitability of Zylon fabric as a barrier against uncontained aircraft engine fragments.
  - ***Accomplishments (Phase 1)- (FY-02/03)***
    - Completed ballistic testing at UCB and SRI to determine material characteristics
    - LS DYNA material model developed by SRI used by Boeing to predict ballistic test results
    - Completed independent Zylon aircraft compatibility material testing at Boeing
    - DOT/FAA/AR-04/40,P1-3 report
  - ***Status Aircraft Testing (Phase 2)-(FY-04-05)***
    - Optimize aircraft attachments designs on small scale ballistic testing at UCB
    - Conduct full-scale fuselage testing at NAWC China Lake with Boeing designed fabric shields. Report in progress.





AACE Technology Transfer
Multi-Layer Fabric Engine Containment Project

- Team: **ASU (Prof. S Rajan PI),** Honeywell, SRI, NASA-Glenn
  - ***Purpose-*** To develop an accurate LS DYNA3D model for engine containment systems
  - ***Accomplishments (Phase 1) -***
    - Completed static testing at ASU and SRI
    - Completed ballistic testing at NASA Glenn as part of NASA Engine Containment Program
    - Completed computational analysis at Honeywell and SRI of ballistic testing with excellent correlation.
    - DOT/FAA/AR-04/40,P1-4 report
  - ***Status (phase 2)***
    - This phase will refine ballistic testing to more represent engine blade-out condition
    - Containment ring testing is currently underway at NASA Glenn



FAA Certification Support
LS-DYNA Modeling Quality Control

- **New AACE Project started in FY-05**

- **Team: George Washington University (GWU) (Dr. S. Kan PI),** Livermore Software Technology Corp (LSTC), Silicon Graphics Inc. (SGI)
- *Purpose*- Provides more accurate modeling of impact and penetration for engine containment and fuselage barrier designs.
  - Provide direct support to the LS-DYNA Aerospace Quality Control Working Group
  - Direct benefit to FAA Certification by establishing modeling standards
  - Provide LS-DYNA training for FAA and industry